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RELATCHABLE LAUNCH RESTRAINT MECHANISM FOR DEPLOYABLE BOOMS

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ABSTRACT

A new Relatchable Launch Restraint Mechanism has been developed which enables a deployable system to be restrained and released repeatedly rather than the normal "one-shot" release systems of the past. The deployable systems are of the "self-extending" type which rely on a lanyard attached to a drive motor to control the deployment and retraction. The Relatch Mechanism uses the existing drive motor to also actuate the latch. The design and kinematics of the Relatch Mechanism as used on two flight programs are herein described.

BACKGROUND

Deployable systems are used for many aerospace applications in which a payload must be held close to the spacecraft for support during launch to prevent damage but must extend out away from the spacecraft to function properly in space. Antennas, magnetometers and solar arrays are examples of such payloads.

Most deployable booms which have been used in space have relied on two separate mechanisms for operation: one for securing the unit for launch and another for deploying and retracting the unit in space. In the past, this launch restraint has been released using one-time-only actuated devices such as explosive bolts or cable cutters.

With the advent of the space shuttle, new requirements are now generally imposed: those of retracting and resecuring the unit in preparation for re-entry and landing.

The mechanism described in this paper not only secures the unit for launch, releases the unit and controls the deployment, but also retracts and relatches the unit using only one motor or drive system. This unlatch-deploy-retract-relatch sequence can be repeated many times thus allowing reliability testing of the system by using the actual flight components.

LATCH DESIGN REQUIREMENTS

The purpose of the Relatch Mechanism is to avoid pyrotechnic release of launch restraint devises on aerospace systems. The Relatch Mechanism is a reliable alternative to cable cutters or explosive bolts especially in applications which must be operated repeatedly in order to show reliability or be relatchable in preparation for retrieval and re-entry. Also, the hazards associated with the use of pyrotechnics are completely avoided; and, since the unlatch process is nondestructive, there is no need to replace any components between cycles.

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Another disadvantage of pyrotechnic actuators is that to justify reliability, many samples must be tested and accurate batch control maintained. After each deployment cycle, the pyrotechnic device must be replaced. The Relatch Mechanism, however, has proved its reliability and repeatability by successful operation for many repetitions at high and low temperatures and at various motor voltages using the same components which will be used for flight.

The Relatch Mechanism was specifically designed to secure a self-deploying lattice structure of the type used to extend sensitive instruments away from the spacecraft. When the boom is fully retracted and latched, it is capable of withstanding the loads induced by the vibration of launch. Once the boom is in space, it is required to unlatch and deploy. The latch is designed so that the axial forces from the center post due to the preload in the boom do not act in a way to unlatch or release the system. The launch loads, therefore, are taken by the center post and latch assembly and not by the lanyard and motor which are, in fact, unloaded when the latch is engaged.

The motor-drive system is used here to restrain the mast from deploying too fast and also to facilitate retraction. The Relatch Mechanism uses this existing drive system to also actuate the latch so that there are fewer active components in the system. Although a specific drive was used in this system, a wide variety of motor-drive combinations would work equally well to actuate the mechanism.

SYSTEM DESCRIPTION

The complete system consists of the self-extending boom, motor-drive assembly, restraining lanyard, and the latch mechanism (Figure 1.). When fully deployed, the mast straightens out to form a very strong and stiff triangular lattice structure. When retracted, however, it is a loose coil which must be constrained somehow in order to survive the vibration of launch. The most effective way to do this is by confining the retracted mast in a thin cylindrical shell (or canister) with end plates. This constrains the mast in the radial and axial directions.

The bottom of the mast is attached to the base plate which is in turn attached to the spacecraft. In this way, the mast has a fairly direct load path to the spacecraft which gives good root support.

The top of the mast is attached to the top plate onto which the payload is mounted. When the mast deploys, the top plate, along with the payload, moves away from the canister/bottom-plate assembly.

The cylinder and base plate, therefore, form a cup or "canister" and the top plate is the lid. To secure this enclosure for vibration, the lid must be fastened down and then released when the mast is ready to be deployed. This can be done either "externally" in the way of clamps or bands or "internally" by means of a central rod or post down the middle of the canister through the retracted mast. There is, in fact, adequate clearance down the middle of a retracted mast which is usually reserved for the lanyard that restrains the mast during deployment. This second method of internally securing the top plate was chosen for the Relatch Mechanism because it uses a single, centrally located probe on to which a latching device could be engaged.

Figure 1. The Relatch Mechanism was designed to work with a self-deploying triangular lattice column that is capable of retracting to a small fraction of its deployed length. The mast must be restrained during deployment to prevent damage to the boom or payload. The lanyard is a metal ribbon, used as a tether, which runs down the middle of the mast.

The top end of the lanyard is attached to a bridle system which controls the last bit of deployment and makes it possible to retract the mast by simply pulling on the lanyard. When the mast is fully deployed, the lanyard is slack so as not to affect the mast properties. The other end of the lanyard is attached to the motor drive system. When the motor is driven one way, the mast deploys. When polarity to the motor is reversed, the mast retracts.

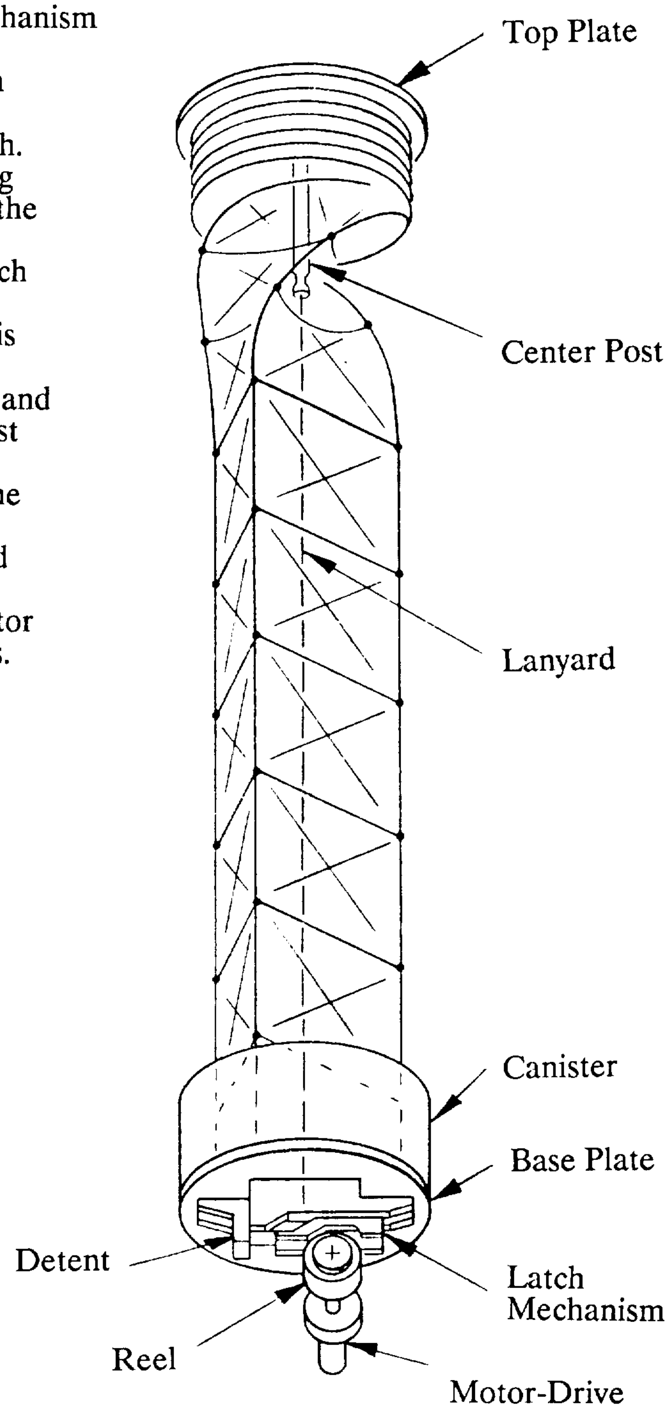

Figure 1. SYSTEM COMPONENTS

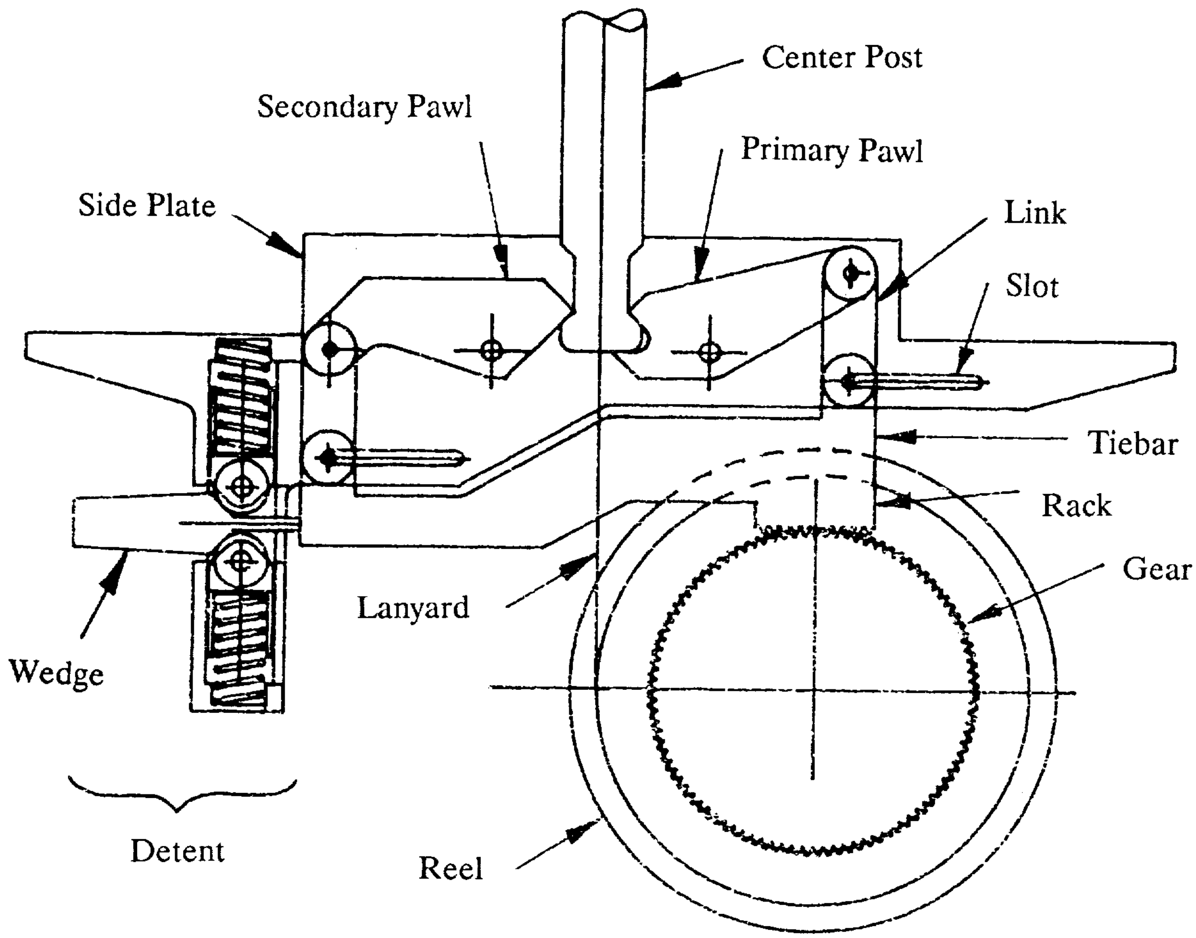

Figure 2. LATCH COMPONENTS

Figure 2. The Relatch Mechanism, together with the center post, holds the deployable boom together during vibration. The center post is attached to the top plate, the latch is mounted to the bottom plate, and the mast is captured in between. The Relatch Mechanism is designed so that the axial forces from the center post as a result of the preload on the boom do not act in a way to unlatch or release the system. The center post is captured by two pawls which are supported in turn by twin links to the tiebar. Since the links are parallel to the main direction of force and are in compression, the mechanism is able to restrain large forces as long as the tiebar constrains the ends of the links. The axial forces in the links are transferred to the side plate or chassis through dowel pins which are able to slide in the slots in the side plate. The slots also limit the travel of the tiebar.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

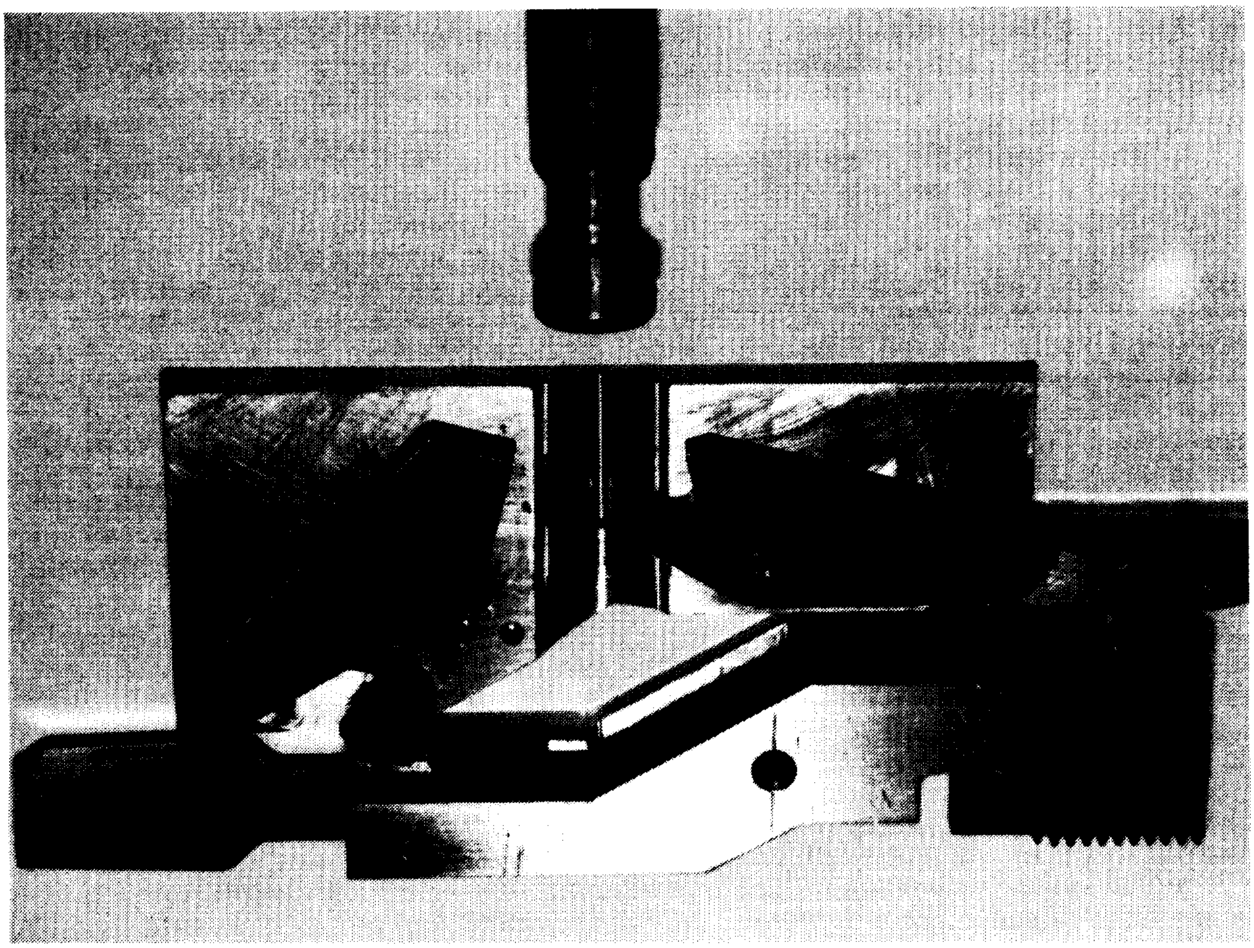

Figure 3. UNLATCHED POSITION

Figure 3. This photograph of the development unit shows the Relatch Mechanism in the unlatched position. This unit has been cycled over 300 times in the engineering mast.

LATCH FUNCTION

Power applied to the motor-drive system rotates the reel assembly, thus moving the tiebar. This pulls the wedge through the detent and at the same time positions the latch pawls to release the center post. If the center post is restrained for some reason, the tongue on the primary latch pawl pushes on the center post to initiate deployment. After the rack clears the gear, the slight taper on the wedge causes the tiebar to travel to the end of the slot (called the unlatched position). Limit switches indicate the latched or unlatched position.

The motor-drive system continues to rotate the reel assembly which pays out the lanyard thus controlling the deployment of the mast. This continues until the mast is fully deployed and the limit switches cut off power to the motor.

Retraction of the unit is the most important action performed by this mechanism and best illustrates the function of the system. The drive motor pulls on the lanyard which initiates retraction. Continued operation of the motor retracts the mast until it is fully stowed. The objective of the design is to allow the motor to decouple from the retract process in order to actuate the latch. This is achieved by using a spring loaded reel (Figure 4.) which allows the drive to continue to rotate and thus actuate the latch while continuing to hold the lanyard and therefore the mast. At the same time, the center post contacts and pushes the tongue on the primary latch pawl, which causes the tiebar to move and the rack to engage into the gear. To prevent any possibility of jamming, the first tooth on the rack is spring-loaded to synchronize the rack and gear.

Once the rack is engaged in the gear, the lanyard and center post can no longer retract. The cam, therefore, stops rotating and the hub (which is attached to the drive gear) continues to rotate. The gear drives the rack to move the tiebar which causes the latch pawls to grab the center post and pull on it to preload the system. At the same time, the wedge is driven through the detent which now holds the latch in place. In this way, the launch loads are taken by the center post and latch assembly and not by the lanyard and motor. In the latched position, the connecting links are parallel to the center post so that launch loads do not unlatch the system. The motor can actually be removed when the unit is fully retracted and latched.

The Relatch Mechanism requires a drive unit which could be any combination of a.c. or d.c. electric motor or motors coupled to a gear box to reduce speed and increase torque. The motor-drive system used on both flight booms is called a "Dual-Drive" which is a reliable, redundant drive mechanism developed for space applications. In this mechanism, two independent motors are used to drive opposite sides of a harmonic gear set, which converge at the output shaft to provide low speed and high torque. In this way, either of two separate drive trains may be used to power the unit.

This mechanism is referred to here as a follow-up on previous design work. The Dual Drive was presented in a paper at the 16^{th} AMS in 1982.

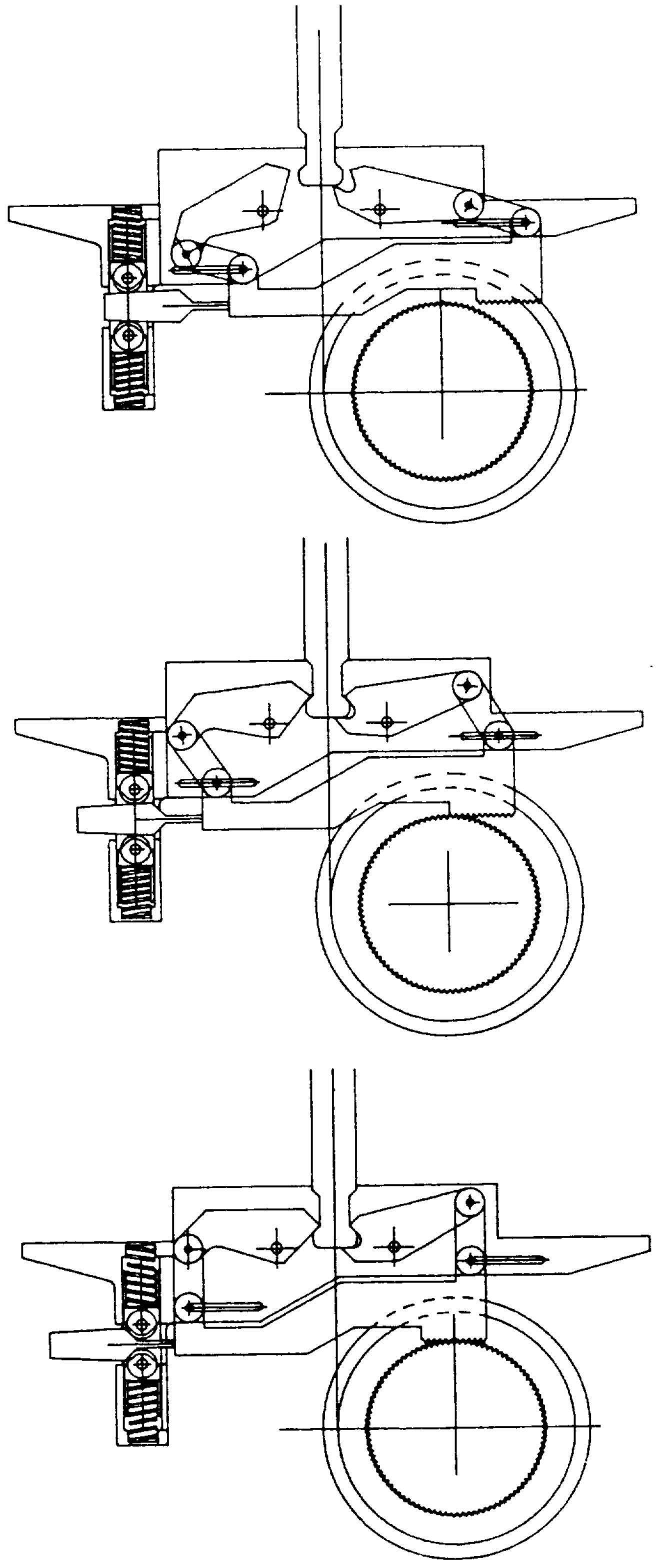

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Figure 3a. LATCH SEQUENCE

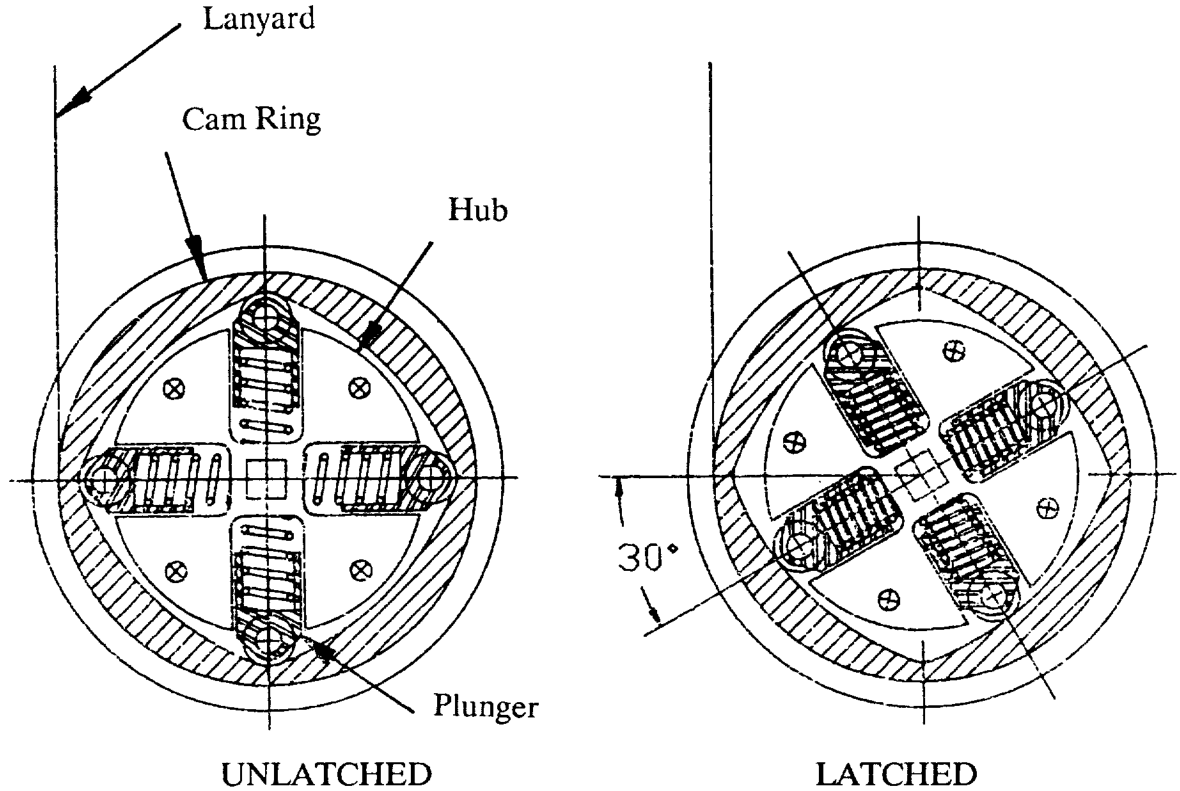


Figure 4. REEL ASSEMBLY

Figure 4. The reel is attached to the motor and to the lanyard. When the motor is driven one way, the mast deploys; when polarity to the motor is reversed, the mast retracts. The reel assembly allows the required differential travel between the lanyard, which stops at full retract, and the gear, which must continue to rotate in order to actuate the latch. When the center post contacts the primary latch pawl, the cam ring is prevented from rotating but the hub is able to continue to rotate.

The reel assembly contains four spring-loaded plungers which roll on a specially shaped cam ring. The cam is shaped to reduce tension on the lanyard as the latch is actuated. The hub of the reel is directly attached to the motor-drive and also to the drive gear. The cam is rotationally positioned by the spring plungers which compress when torque is applied to the cam thus allowing the hub to continue to rotate for another 30 degrees.

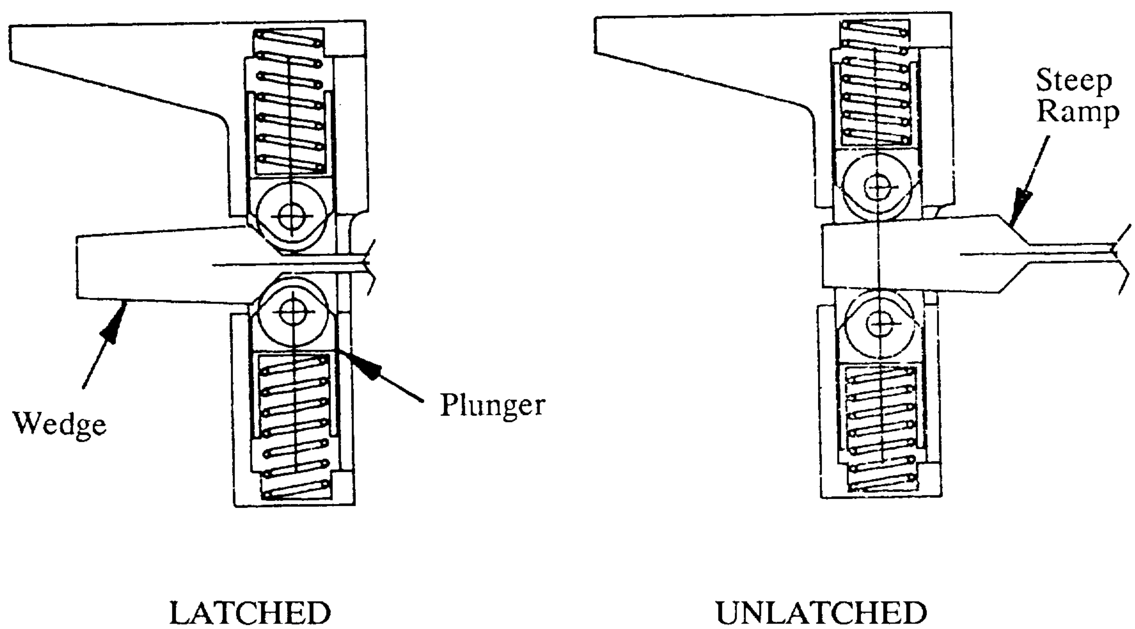


Figure 5. DETENT

Figure 5. The detent holds the tiebar in the fully latched position during vibration. By incorporating a detent mechanism into the latch, the drive motor is not subject to the vibration loads of launch. When the Relatch Mechanism is actuated, the wedge is pulled through the plungers and is then pushed out of the way. The steep ramp on the wedge was designed to assist the motor to preload the boom.

Figure 6. The self-deployable booms thus far used have been of the triangular lattice type which are made up of unidirectional fiberglass rods, bonded aluminum fittings and various fasteners. This type of mast has been used for the past 25 years because it is lightweight, strong and stiff, and retracts to a fraction of its length. Two flight units have used the relatch mechanism to reduce overall system complexity and weight.

The first program was the ZEPS (Zenith Energetic Particle Spectrometer) boom for the UARS (Upper Atmosphere Research Satellite) which was built for General Electric. The ZEPS boom uses a 12.5 inch diameter mast which extends to 15 feet. The second program was the MDRA (Mast Deployment Retraction Assembly) for the Explorer Platform which was built for Honeywell. The MDRA boom uses a 17.5 inch diameter mast which extends to 5 feet. The two programs are similar in that both are based on lanyard-restrained, coilable retractable lattice columns.

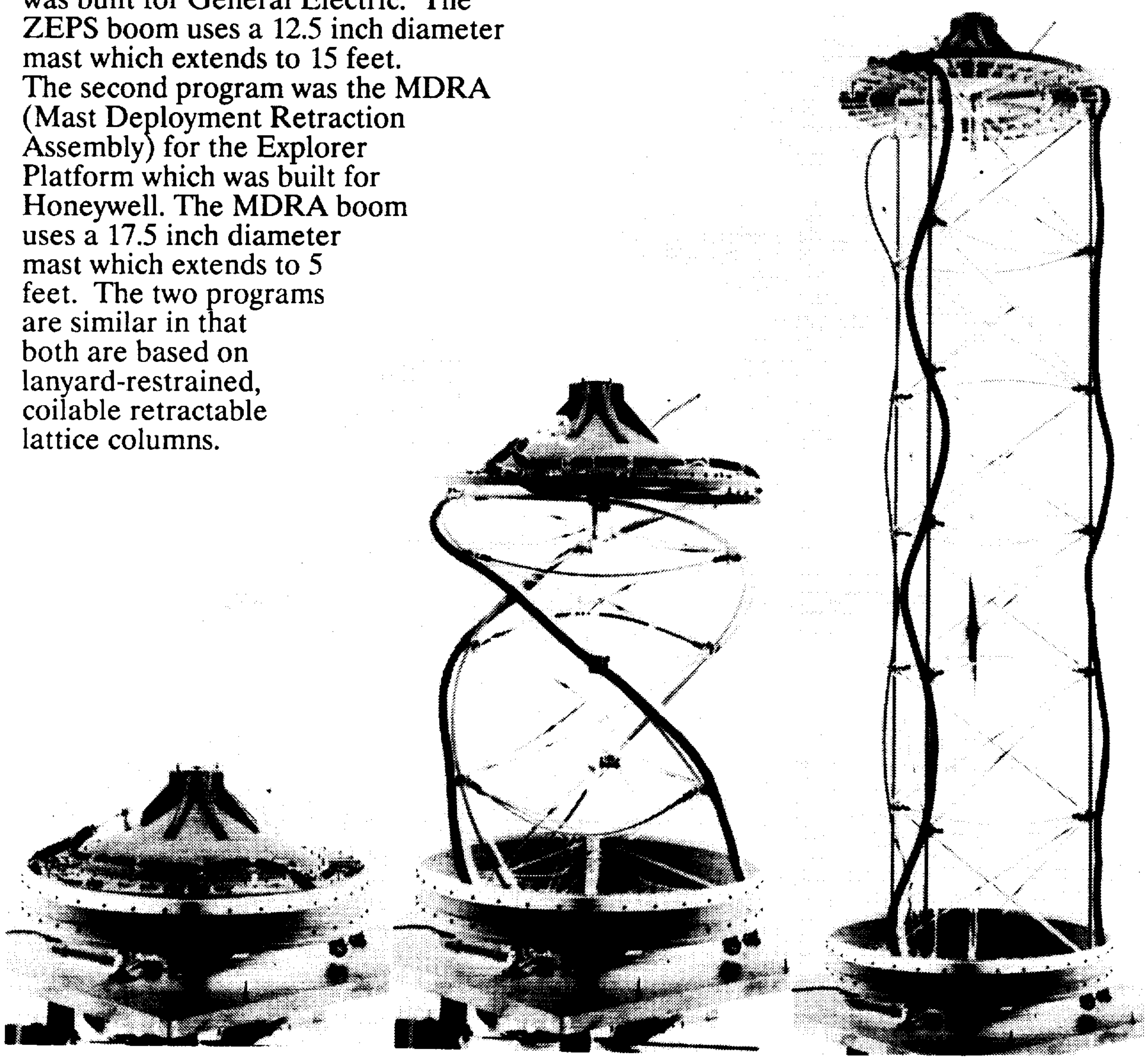


Figure 6. DEPLOYABLE MAST

TEST DATA

Two years of development and testing have gone into the design and manufacture of the Relatch Mechanism. The first part of the development involved designing and redesigning the mechanism to satisfy the requirements of the functional kinematics. In other words, making it work. After the basic configuration was defined, an engineering development unit was manufactured and tested. This unit functioned without problems, successfully latching and unlatching under various conditions.

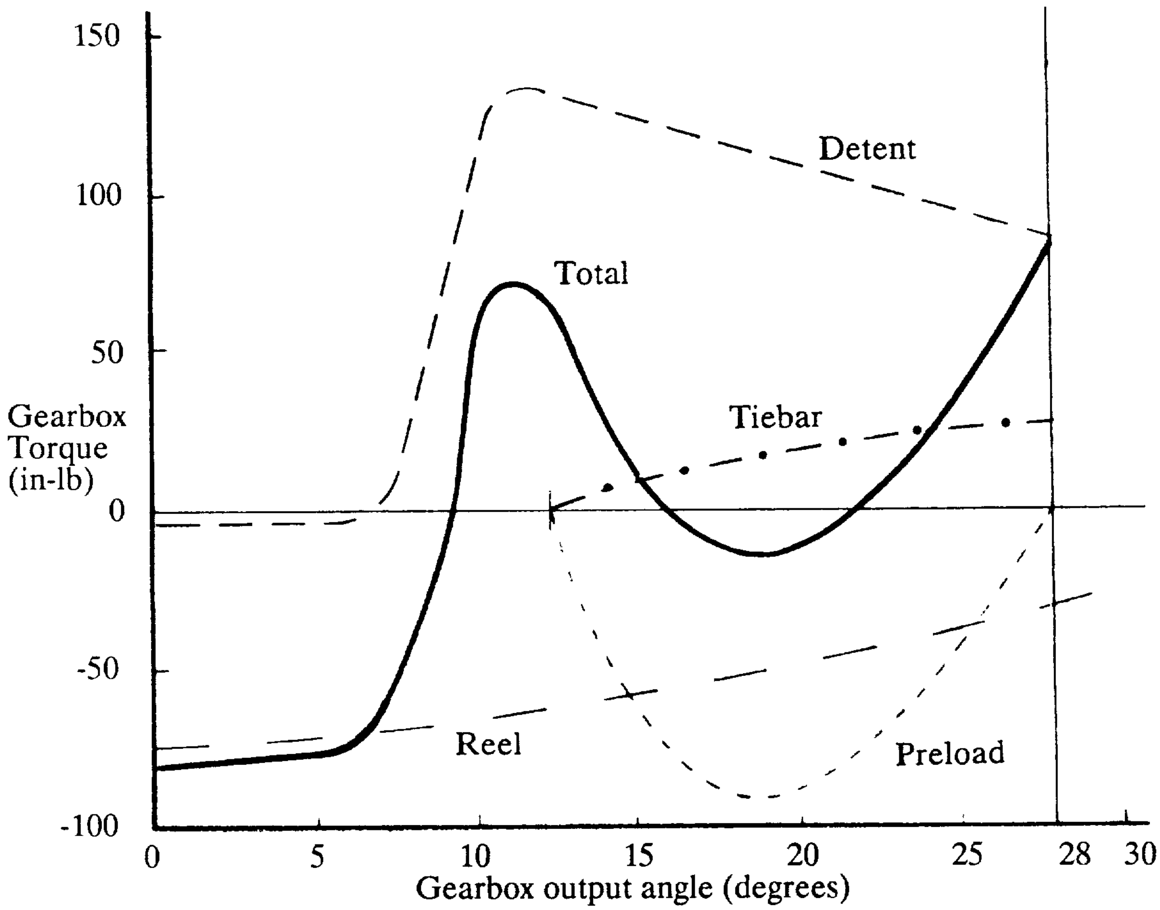
The flight units were designed and manufactured based on the configuration of the development unit. These units also performed well except that the initial chart-recorder traces from the first flight unit showed higher than expected latching torque values. The Relatch Mechanism was analyzed to determine the source and components of the forces with the hope that one component could be easily modified to bring down the peak force. The actual relatch/unlatch profile was determined to be the sum of the force curves from four main components:

A. REEL ASSEMBLY spring force and friction
B. DETENT - spring force and friction
C. PRELOAD - linkage force, neglecting friction
D. TIEBAR - sliding and rolling force of latch

Latching occurs when the mast is retracted; unlatching occurs when the mast is deployed. As shown in the graphs on the following pages, some forces add to the total and some subtract. The latching and unlatching functions were both analyzed because by modifying one component to improve the latch function, the unlatch function could be made worse. The detent was the most obvious choice to be modified, and the force traces show the final results

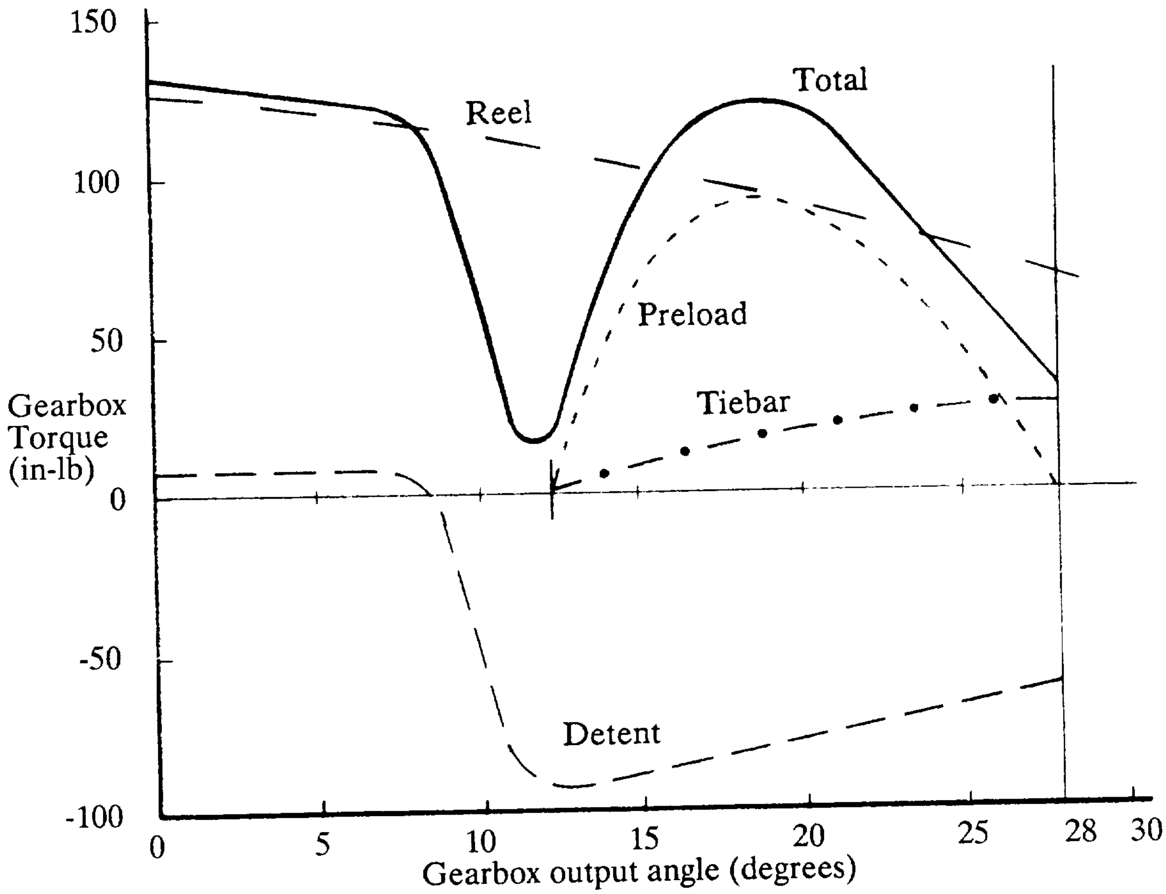
The test data is presented as Torque versus Angle at the gearbox output shaft. The theoretical total is the sum of the above force components which operate in different directions: the preload force acts in the Z axis, the latch friction and detent act in the X axis, and the reel and drive system act in an angular axis. To more easily understand and analyze the various force components of the system, the force diagrams were converted into units of 0 to 30 degrees motion at the reel which corresponds to the fully unlatched to fully latched position. Although the reel is capable of 30 degrees of travel, the Latch Mechanism only requires 28 degrees.

The actual force trace was taken from the motor leads at 28 volts d.c. and is presented as Current versus Time.

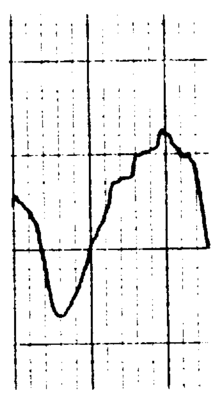


TOTAL FORCE, Deploy (Unlatching)

ACTUAL FORCE TRACE, Deploy



TOTAL FORCE, Retract (Latching)



ACTUAL FORCE TRACE, Retract

TEST RESULTS

Three latch mechanisms have been integrated and tested in deployable booms. The first was the engineering development unit which was built essentially as conceived and went through extensive testing.

Two problems, however, occurred in the flight versions which were not experienced in the engineering development unit. The preload for the flight units was much higher than the development unit and the flight motor was not as powerful as the development motor. To get more work out of a smaller power source, some creative engineering was needed to solve the problems which were generated by these changes.

The first problem was an increased latching force as indicated on the chart recording of the motor current. The first few cycles were within specification but, on subsequent cycles, the motor current was much higher. The cause of the increased motor torque was difficult to isolate because when the system is assembled, it operates as a unit with many forces acting at once. A decision was made to disassemble the system and examine the components for abnormalities. After careful examination, the slot in the side plate of the latch mechanism was found to have some galling on the loaded surface caused by the dowel pin sliding under the increased preload. To handle the increased sliding force, the slot was enlarged and a small roller was added which could handle the load while reducing the sliding force. This change was tested and proven on a modified development unit and incorporated into the flight units.

The second problem was that the motor did not have a large enough margin of safety. To assist the motor, the wedge in the detent was re-shaped to help the motor in the final part of latching where the preload is achieved. Although this change sounds simple, detailed analysis was required to properly shape the wedge and size the detent springs.

CONCLUSION

The Relatch Mechanism has been demonstrated to be a reliable alternative to releasing devices such as cable cutters or explosive bolts, especially in applications which must be operated repeatedly to show reliability or be relatchable in preparation for retrieval and re-entry.

In addition to the vibration requirements, the Relatch Mechanism also functioned repeatably and reliably at high and low temperatures and various motor voltages.

ACKNOWLEDGEMENT

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